Large Scale Finite Element Simulation and Modeling Using GIS/CAD for Environmental Flows in Urban Area

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Summary

A large-scale computer modeling and simulation method is presented for environmental flows in urban area. Several GIS and CAD data were used for the preparation of shape model and an automatic mesh generation method based on Delaunay method was developed. Parallel finite element method based on domain decomposition method was employed for the numerical simulation of natural phenomena. The present method was applied to the simulation of flood flow and wind flow in urban area. The present method is shown to be a useful planning and design tool for the natural disasters and the change of environments.

1 Introduction

A number of natural disasters occur annually in various parts of the world. Especially, a number of natural disasters in cities increases in accordance with the development of city area, such as flood, wind disaster and air pollution. In order to estimate the extent of a disaster quantitatively, it is necessary to estimate the behavior of natural phenomena which causes the natural disaster. In practical computations of this type of problems, the computational domain is large and the computations need to be carried out over long time durations. Therefore, this type of problem becomes quite large-scale and it is essential to use methods which are as efficient and fast as the available hardware allows.

In recent years, massively parallel finite element computations have been successfully applied to several large-scale simulations for natural phenomena. These computations demonstrated the availability of a new level of computational capability to solve practical problems. However, in order to compute natural phenomena accurately, it is necessary to prepare an accurate shape model for landform, buildings and civil structures. Furthermore, a good finite element mesh of quality must be prepared for the complicated spatial analytical domain.

In this presentation, a large-scale computer modeling and simulation method is presented for environmental flows in urban area. Several GIS and CAD data were used for the preparation of shape model and an automatic mesh generation method based on Delaunay method (Tagiguchi (1992)) was developed. In order to express the geographical features accurately, the valley and ridge lines are expressed by an edge of the element. ArcView and AutoCAD are employed for the GIS and CAD systems respectively. Parallel finite element method based on domain decomposition method and MPI was employed for the numerical simulation of natural phenomena. The P1/P1 element (triangular element for 2D problem, tetrahedral element for 3D problem) was employed for the finite element. The stabilized finite element formulation based on SUPG/PSPG (Tezduyar (1991)) was employed for the discretization in space. The present method was applied to the simulation of flood flow and wind flow in urban area. The shallow water equation and the Navier-Stokes equation were employed for the governing equations. The present method is shown to be a useful planning and design tool for natural disasters and the change of environments.

2 Modeling System for Landform and Urban Area

2.1 Modeling for Landform

Figure 1 shows the flow chart for the modeling system for landform. For the data of land elevation, the digital elevation map issued by the Japanese geographical survay institute was employed. The reolution of the map is 50m. The ArcView (Razavi, A.H.(1999)) was used for the GIS system.

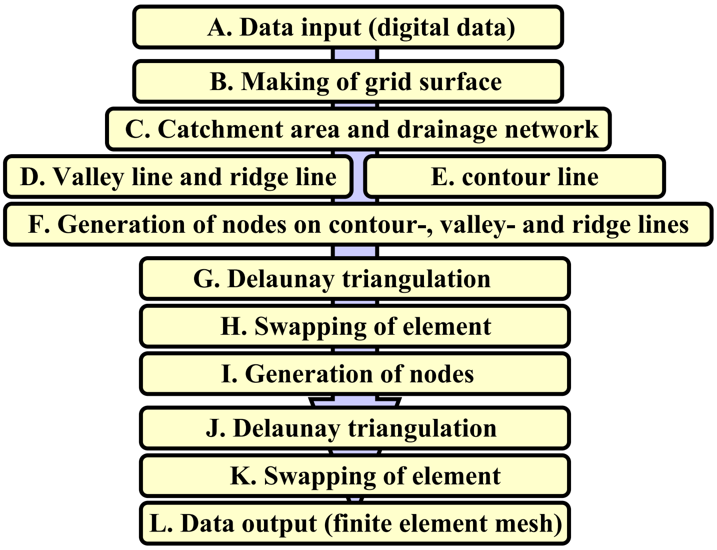

Figure 1 Flow chart

2.1.1 Making of vally- and ridge-line information

Using the data of elevation map, a more fine grid was created by third order spline interpolation method. The grid is refered as the grid surface and the grid size was assumed to be 10m. Figure 2 shows the grid surface and contour line for the studied area. The information of vally and ridge line are created by the function of ArcView using the elevation data of grid surface. Figure 3 shows the contour-, valley and ridge lines.

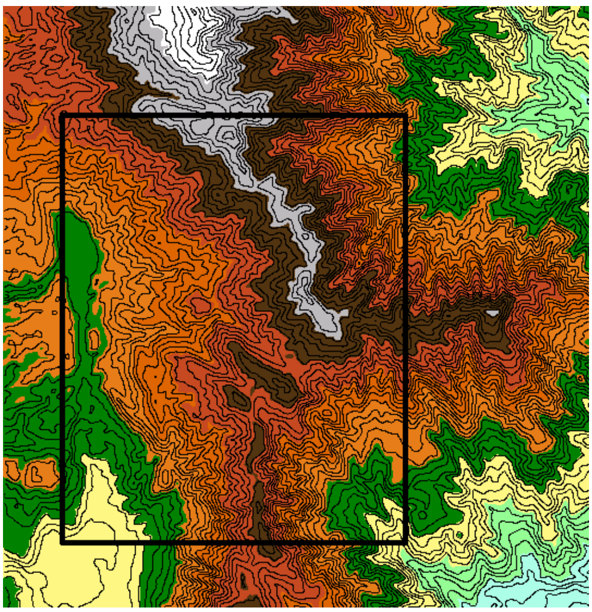

Figure 2 Grid surface and contour line for studied aea

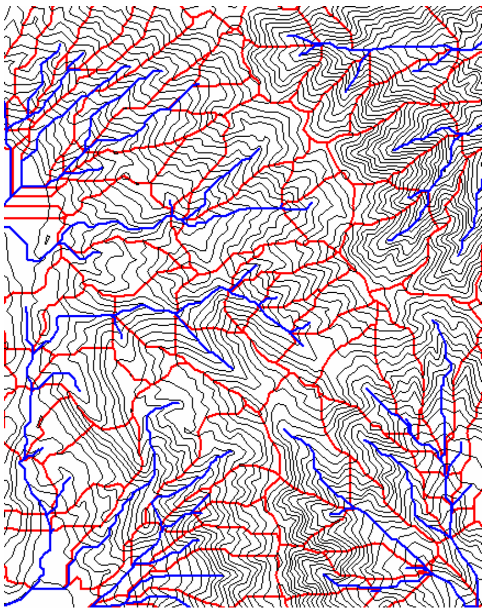

Figure 3 Contour line, valley and ridge lines

Next, the line data was vectorized by the raster-vector transformation. The nodes are generated on the contour, valley and ridge lines at the regular intaval. The elevetation of nodes on the valley and ridge lines are obtained by superposing the elevation data of grid surface. Figure 4 shows the node distribution at the local part of the studied area. Each nodes has the data for plane coordinate and elevation, and the property for line type.

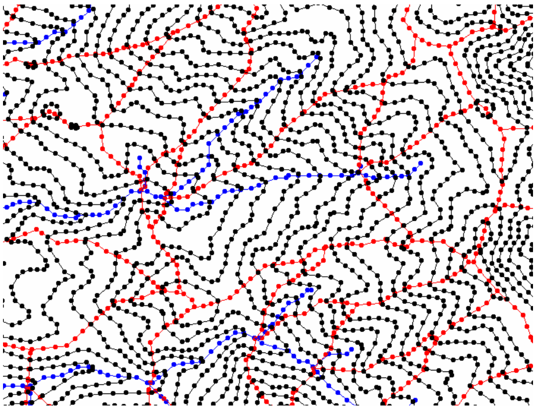

Figure 4 Generation of nodes

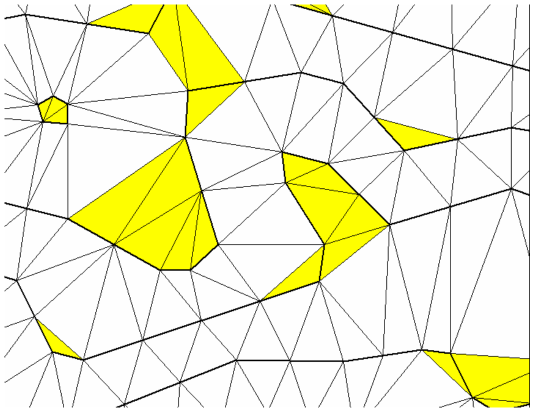

Figure 5 Occurence of artifitial terraced paddy field

2.1.2 Delaunay triagulation and swapping algorithm

Using the information of nodal points, the surface mesh based on the triangular element was created by the modified Delaunay triangular method (Taniguchi (1992)). Using the property of line data, the contour line, valley and ridge lines can be determined as "break lines" and these lines are expressed by an edge of finite element. From this, the geographical features can be expressed accurately. However, the artificial terraced paddy field will appear by the triangulation using the three nodes which have same elevation data as shown in Figure 5. In this figure, the shadow elements denote the elements of terraced paddy field. In order to avoid the element "artificial terraced paddy field", a swapping algorithm for the edge of triangular mesh was presented.

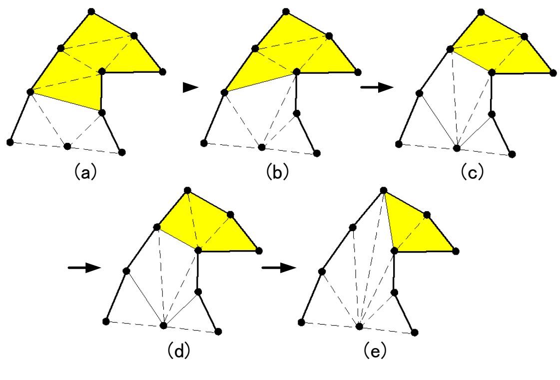

Figure 6 Swapping algorithm

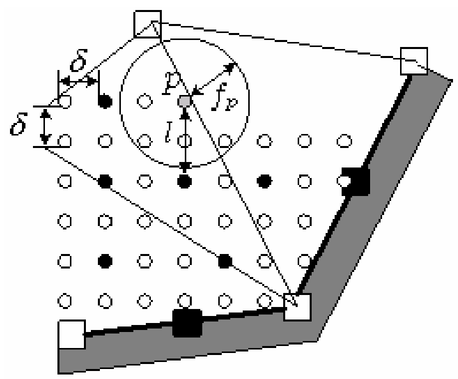

Figure 7 Generation of new nodes

Figure 6 shows the swapping algorithm. At first, the element which has three same nodal elevations is searched (Figure 6 (a)). If the edge is not on the contour, valley and ridge lines and is not faced to the element of terraced paddy field, the edge is swapped (see Figure 6 (b), (c)). In the case the swapping algorithm can not be applied as shown in Figure 6 (c), the inside edge surrounded by the element of paddy field is swapped as shown in Figure 6 (d). Then, the one more element of terraced parry field will disappear as shown in Figure 6 (e). Figure 8 shows the flow chart for the swapping method.

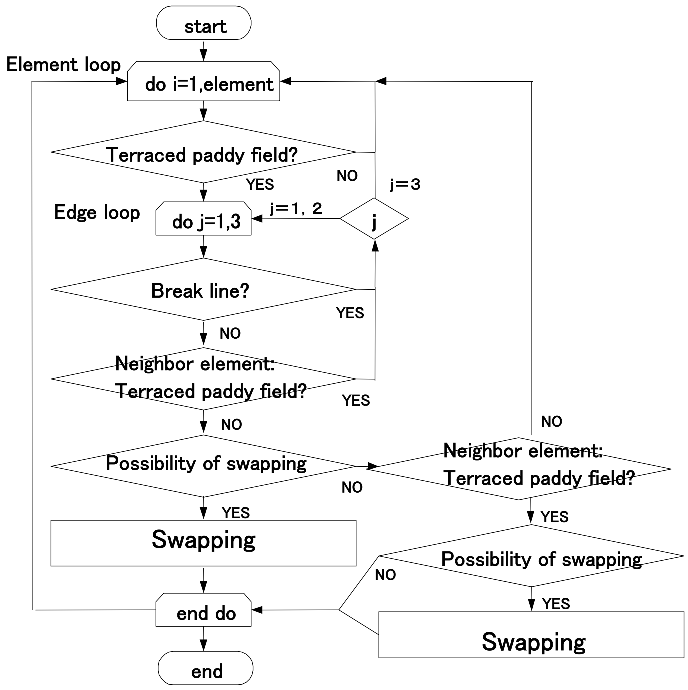

Figure 8 Flow chart for swapping algorithm

2.1.3 Geneation of new interior nodes

In order to avoid the vent element, the new interior nodes are generated. The reason of the occurrence of the vent element is that the finite element mesh was prepared by the nodes on contour-, valley and ridge lines only. The vent element influences the numerical accuracy and stability. The generation of new nodes is investigated at intervals δ from the bottom line to the upward direction as shown in Figure 7. In Figure 7, f_p is the element size function at node P and l denotes the distance from P to its closest existing node. If f_p is smaller than l, the node P can be accepted as a new interior node. The black circles represent the existing interior nodes which satisfy the above criterion, while white circles represent the nodes omitted and the squares represent the nodes on the contour-, valley and ridge lines. Figure 9 and 10 shows the finite element mesh and the shape model for landform. From these figures, it can be seen that the finite element model expresses the geometrical features accurately. Introducing information of valley and ridge line, the swapping algorithm and generation of nodes, the ratio of elements of terraced paddy field and total number of elements was greatly reduced from 16.3% to 0.16%.

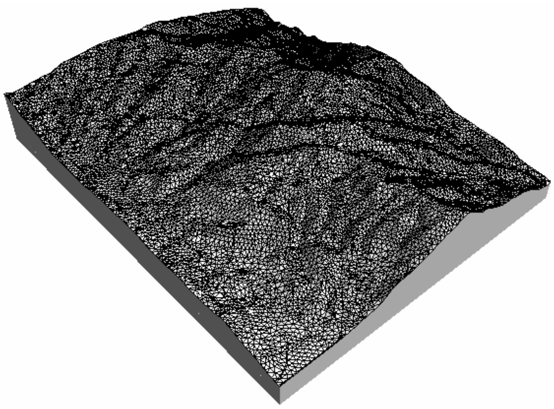

Figure 9 Finite element mesh

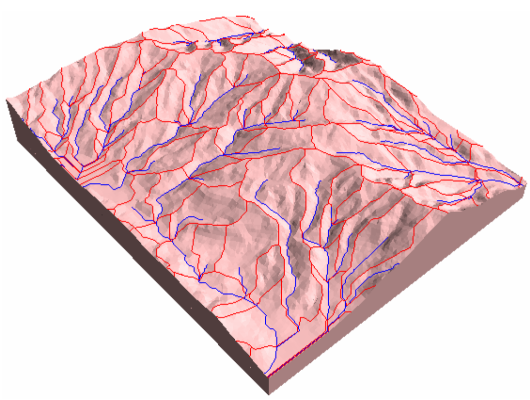

Figure 10 Shape model for landform

2.2 Modeling for Urban Area

The modeling system for urban area is expressed in this section. In case of the modeling of urban area, the building data is needed in addition with the elevation data. For the data for buildings, the 2D and 3D GIS data obtained by the aerial-photo and -laser surveying were employed.

2.2.1 2D modeling for urban area

The 2D finite element model for flood flow analysis was prepared. For the data for buildings, the 2D GIS data (Mapple 2500) obtained by the aerial-photo was employed. For the data of land elevation, the digital elevation map issued by the Japanese geographical survey institute was employed. Figure 11 shows the contour line and the polygon for buildings after the superposition of both digital elevation map and 2D GIS data for buildings. In case of the modeling of urban area, the nodes are generated on not only the contour line, valley and ridge lines but also the boundary of the building as shown in Figure 12. In this example, the valley and ridge lines are not considered as break lines. The way to make a surface mesh is one and the same as the method described in the section 2.1. Figure 13 shows the finite element mesh for the studied area. The mesh size was assumed to be 2m. Figure 14 shows the details for the finite element idealization around the river.

Figure 11 Contour line and polygon for buildings

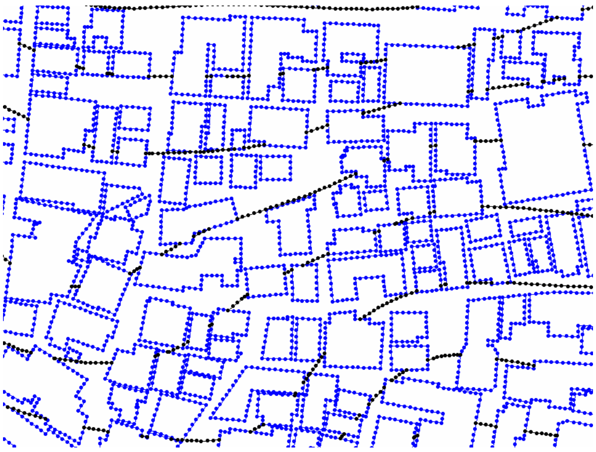

Figure 12 Nodes on contour line and boundary of building

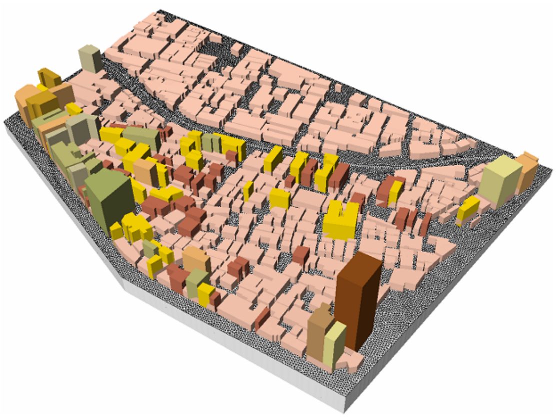

Figure 13 Finite element mesh

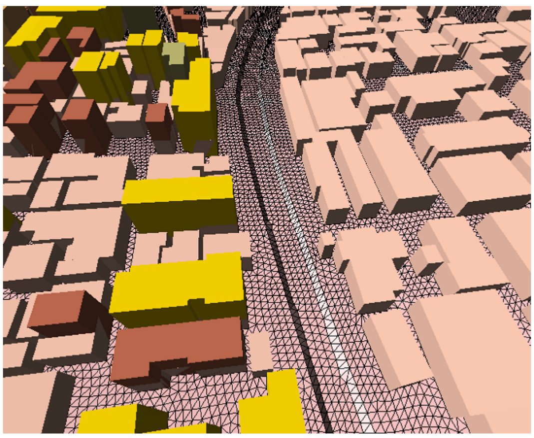

Figure 14 Finite element mesh around river

2.2.2 3D modeling for urban area using 2D GIS data

The 3D finite element model for wind flow analysis was prepared by using the 2D GIS data (Mapple 2500). For the data of land elevation, the digital elevation map issued by the Japanese geographical survey institute was employed. Figure 15 shows the surface mesh around Shinjuku-area, Tokyo. The vertical shape for low-storied buildings was assumed to be straight and that for the high-storied buildings were prepared by the CAD system (Auto CAD). In Figure 16, the color buildings indicate the buildings prepared by the CAD system.

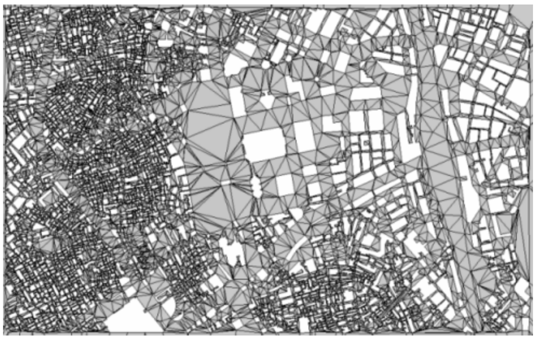

Figure 15 Surface mesh for Shinjuku area

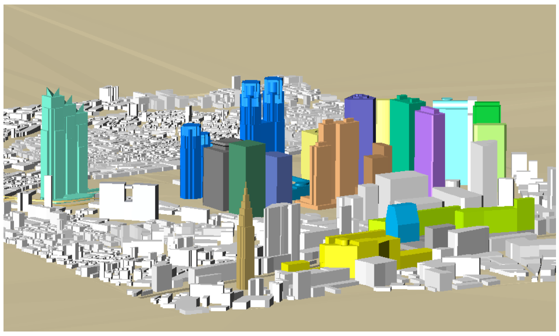

Figure 16 Shape modeling using CAD system

2.2.3 3D modeling for urban area using 3D GIS data

The 3D finite element model for wind flow analysis was prepared by using the 3D GIS data (Map Cube). For the major cities, the 3D GIS data was prepared in Japan. Figure 17 shows the 3D GIS data around Ebisu, Tokyo. The 3D GIS data was obtained by the laser surveying. This data contains the surface data for not only the housing and buildings but also the landform accurately. However, data concerning public facilities such as expresswayes are not available. So, the public facilities are added by using CAD system. Figure 18 shows the 3D shape model after adding the expressway.

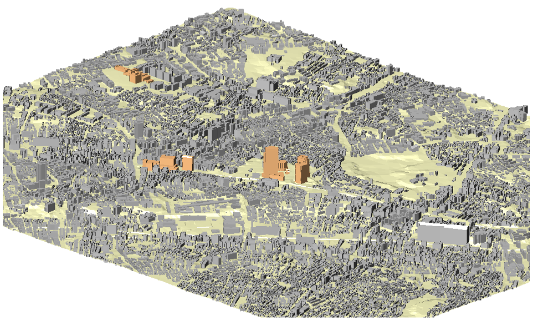

Figure 17 3D GIS data for Ebisu, Tokyo

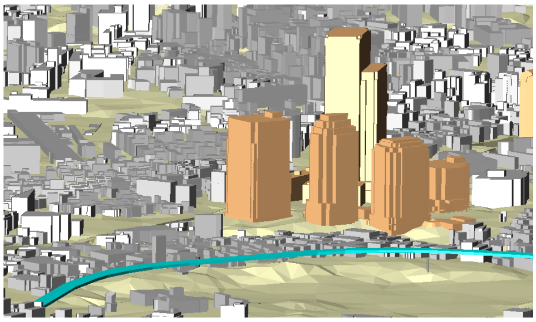

Figure 18 3D shape model after adding expressway

3 Finite Element Simulations

The stabilized finite element method was employed for the simulation of envirnmental flows in urban area. The finite element mesh obtained by the present method were applied to the simulation of flood flow and wind flow in urban area.

3.1 Flood Flow Simulation

For the flood flow simulation, the shallow water equation was employed for the governing equations. The stabilized finite element formulation based on SUPG was employed for the discretization in space. For the discretization in time, the explicit Euler method was employed. In order to treat the moving boundary, the Eulerian approach was applied (Kawahara and

Umetsu(1986)). The finite element mesh shown in Figure 13 was employed for the simulation. The total number of elements and nodes are 33,223 and 53,272 respetively. For the boundary condition, the discharge was assumed at the inlet of river. Figure 19 shows the computed water elevation at t=3 hours. It can be seen that the flood occur in accordance with the increase of river discharge.

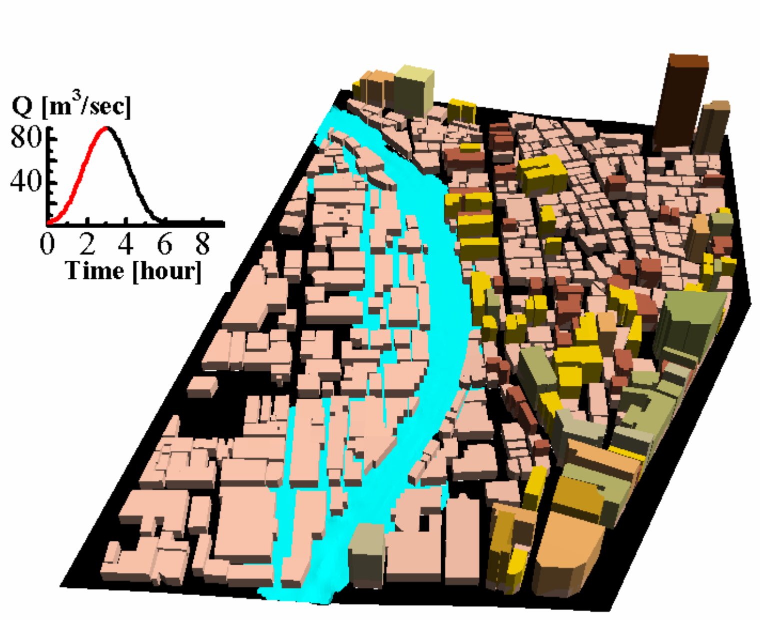

Figure 19 Computed water elevation at t=3 hours

3.2 Wind Flow Simulation

For the wind flow simulation, the Navier-Stokes equation was employed for the governing equations. The finite element mesh based on the tetrahedral element was prepared by using the 3D shape model shown in Figure 16. The total number of nodes and elements were 2,868,335 and 15,871,126 respectively. The stabilized finite element method based on SUPG/PSPG (Tezduyar(1991)) was employed for the discretization in space, and the Crank-Nicolson scheme was employed for the discretization in time. The parallel computational method based on domain decomposition and MPI was employed. Figure 20 shows the doman decomposition for 20 sub-domains. The PC cluster used consists of 20 nodes, each with a Intel-Xeon 3.06 GHz processors and 2GB memory.

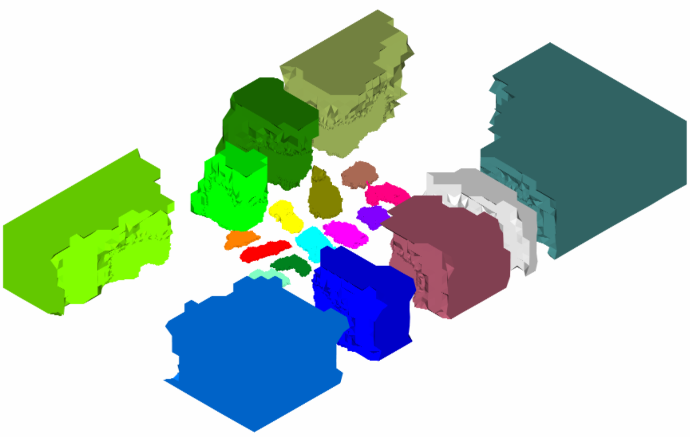

Figure 20 Domain decomposition

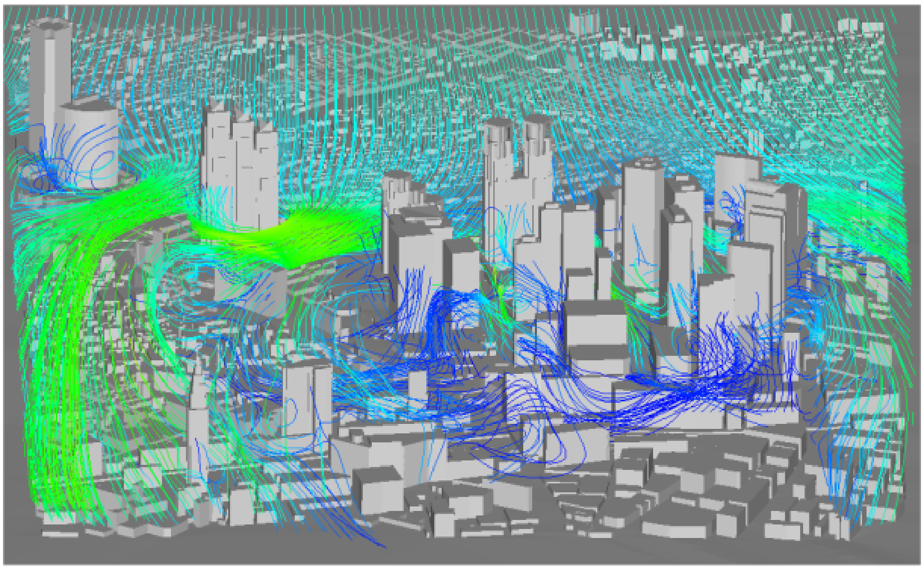

Figure 21 Computed streamline

The verification of the finite element solver has been done by the comparison with experimental data. (Kashiyama, K., Shimizu, T. and Taniguchi, T. (2003), Kashiyama et al.(2004)). Figure 21 shows the computed stramline. From this figure, it can be seen that the wind flow passed a large buildings shows the complicated flow field.

4 Conclusions

A large-scale computer modeling and simulation method for environmental flows in urban area has been presented in this paper. The shape model for landform and buldings can be prepared accurately by using several GIS and CAD data. The automatic mesh generation method based on Delaunay method has been developed. Parallel finite element method based on domain decomposition method has been employed for large scale simulations. The present method has been applied to the simulation of flood flow and wind flow in urban area. From the results obtained in this paper it can be concluded that the present method provides a useful planning and design tool for the natural disasters and the change of environments.

5 References

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